Effect of canal preparation with TRUShape and Vortex rotary instruments on three-dimensional geometry of oval root canals

Arias, Ana ; Paqué, Frank ; Shyn, Stephanie ; Murphy, Sarah ; Peters, Ove A

Abstract: The purpose of this study was to assess the geometry of non-round root canals after preparation with TRUShape (a novel instrument with s-shaped longitudinal design) in comparison to conventional rotary instrumentation using micro-computed tomography. Twenty distal root canals of mandibular molars were randomly distributed in two groups to be shaped with either TRUShape or Vortex rotaries. Percentages of unprepared surface and volume of dentin removal for the entire canal and for the apical 4 mm were calculated. Canal transportation and the structure model index (SMI) were assessed. Data were compared with Student t-tests. Shaping with both techniques resulted in similar prepared surface and volume of dentin removed, as well as the extent of canal transportation. The SMI shape factor was significantly lower for TRUShape preparations (P = 0.04) suggesting less rounding during rotary preparation. Although both instruments were suitable for the preparation of oval canals, TRUShape appeared to better conform to the original ribbon-shaped anatomy.

DOI: https://doi.org/10.1111/aej.12201

Originally published at:
Arias, Ana; Paqué, Frank; Shyn, Stephanie; Murphy, Sarah; Peters, Ove A (2018). Effect of canal preparation with TRUShape and Vortex rotary instruments on three-dimensional geometry of oval root canals. Australian Endodontic Journal, 44(1):32-39.
DOI: https://doi.org/10.1111/aej.12201

Effect of canal preparation with TRUShape and Vortex rotary instruments on three-dimensional geometry of oval root canals.

Arias A,[1,2] Paqué F,[3] Shyn S,[1] Murphy S,[1] Peters OA[1]

Affiliations:

[1] Department of Endodontics, University of the Pacific, Arthur A Dugoni School of Dentistry, San Francisco, CA, USA

[2] Department of Conservative Dentistry, School of Dentistry, Complutense University, Madrid, Spain

[3] Clinic of Preventive Dentistry, Periodontology and Cariology, University of Zurich, Center of Dental Medicine, Switzerland

Correspondence

Dr Ana Arias
Department of Conservative Dentistry
School of Dentistry, Complutense University
Plaza Ramon y Cajal s/n, Ciudad Universitaria, 28040
Madrid, Spain.
Email: aariaspa@ucm.es

Effect of canal preparation with TRUShape and Vortex rotary instruments on three-dimensional geometry of oval root canals

Abstract

The purpose of this study was to assess the geometry of non-round root canals after preparation with TRUShape (a novel instrument with s-shaped longitudinal design) in comparison to conventional rotary instrumentation using micro-computed tomography. Twenty distal root canals of mandibular molars were randomly distributed in two groups to be shaped with either TRUShape or Vortex rotaries. Percentages of unprepared surface and volume of dentin removal for the entire canal and for the apical 4mm were calculated. Canal transportation and the structure model index (SMI) were assessed. Data was compared with Student T-tests. Shaping with both techniques resulted in similar prepared surface and volume of dentin removed, as well as the extent of canal transportation. The SMI shape factor was significantly lower for TRUShape preparations (p=0.04) suggesting less rounding during rotary preparation. Although both instruments were suitable for the preparation of oval canals, TRUShape appeared to better conform to the original ribbon-shaped anatomy.

Key words

micro computed tomography, nickel-titanium rotary instruments, root canal preparation, structure model index, oval root canals

Introduction

One of the established goals of root canal shaping is the creation of a continuous tapered preparation from the apical to the coronal third in all the planes to provide a linear resistance form for a proper obturation (1). The use of nickel-titanium rotary instruments (2) have consistently demonstrated root canal shaping with less straightening, less procedural errors and better centred preparations, when compared to traditional stainless steel instruments and preparing different canal anatomies (3,4). However, a conventional rotary instrument may create a round canal cross-section that does not conform to the reality of many root canal anatomies like those with asymmetrical non-round configurations (5). Moreover, one of the aims when shaping an infected root canal is the removal of the inner layer of dentin (5,6). This task is particularly difficult to achieve in non-round canal anatomies, which cannot be prepared ideally by a rotary or reciprocating conventional system for the fact alone that the instrument at best stays in the canal axis.

A high prevalence of oval canals is reported in the literature (7-9), specifically in certain groups of teeth such as mandibular incisors, maxillary second premolars and distal roots of mandibular molars (7). The preparation of root canals with asymmetrical or oval cross sections resulted in incompletely prepared walls with uncleaned buccal and lingual extensions (5). The presence of concavities and convexities at different levels of the entire root canal length challenges conventional shaping instruments since un-instrumented recesses with remaining debris are left behind (10).

Therefore, the development of new instruments should aim at an equal circumferential preparation of all the root canal surfaces while preserving dentin in order to increase the chance for disinfection without weakening the tooth; hence fulfilling a so-called minimal invasive preparation (11).

The challenging preparation of non-round canals inspired the development of a novel heat-treated nickel-titanium shaping rotary instrument, TRUShape (Dentsply Tulsa Dental Specialties, Tulsa OK) with a characteristic longitudinal s-curve and a 0.06 taper in the apical 2mm that regresses along the overall length. A maximum fluted diameter limitation of 0.80mm limits the removal of dentin in the coronal third aiming at a reduction of teeth fracture susceptibility (12).

Micro–computed tomography (MCT) allows a non-invasive three-dimensional analysis of the root canal system (3) and therefore is an adequate research tool to evaluate the potentials of newly designed rotary instruments and moreover when considering the intricacies of oval root canal preparations (13-16).

The aim of this study was to assess the geometry of non-round distal root canals of mandibular molars after preparation with TRUShape rotary instruments in comparison to conventional rotary instrumentation using well established micro-computed tomography (MCT) scan protocols.

Materials and Methods

Selection of teeth

Twenty human mandibular molars extracted for reasons unrelated to the current study and with similar corono-apical sizes were collected and stored in 0.1% thymol solution at 4°C until further use. Teeth were mounted on SEM stubs and scanned in a desktop MCT unit at an isotropic resolution of 20 μm (μCT 40, Scanco Medical, Brüttisellen, Switzerland) using previously established methods (4,17). Care was taken to specifically select teeth with one distal root canal. Using a web-based algorithm (www.random.org) a total of 20 distal root canals were randomly allocated to each of the two shaping instruments used in the study, Vortex or TRUShape (both Dentsply Tulsa Dental Specialties).

Digital radiographs were taken with two different angulations. Teeth were accessed using highspeed diamond burs and patency of the coronal third of the root canal confirmed. Canal shaping was done by one operator with 20+ years of experience with nickel titanium rotaries (O. P.), according to the manufacturer's guidelines. For the Vortex group, a coronal enlargement was performed with #20/.08 instrument prior to ProLube (Dentsply Tulsa Dental Specialties) lubrication and patency achievement with size #10 K-files (Lexicon, Dentsply Tulsa Dental Specialties). Working lengths (WLs) were set 0.5mm shorter than the radiographic apex. A glide path was then prepared for both groups with Pathfiles 013 and 016 (Dentsply Maillefer, Ballaigues, Switzerland).

Root canal instrumentation with Vortex (group 1)

Using an electric motor, set at 500rpm and 3Ncm, rotaries were used in the following sequence: size #40 /.04 to midroot, #35 /.04 to 2/3 of WL, #30 /.04, #25/ .06 and #30 /.06 to WL.

Root canal instrumentation with TRUShape (group 2)

Using an electric motor, set at 300rpm and 3Ncm, canals were enlarged using #30 /.06*v* to WL.

One ml of 6% NaOCl was applied with a 30g ProRinse needle (Dentsply Tulsa Dental Specialties) placed as deep into the canals as possible without binding after each instrument in either group. After shaping a final flush of 1mL 17% EDTA was applied for 1 min. The operator was not allowed to see the virtual models of reconstructed teeth before preparing the root canals and during the course of the treatment to avoid bias. Preparation was done according to the manufacturer's guidelines with Vortex; such direction for use were established and confirmed during the course of preliminary trials for TRUShape.

Evaluation

Virtual root canal models were reconstructed based on MCT scans and superimposed with a precision better than 1 voxel using VGStudio 2.2 (VolumeGraphics, Heidelberg, Germany) and special evaluation software (IPL, Scanco Medical). Precise repositioning of pre- and post-preparation images was ensured by the combination of the custom-made mounting device and a software-controlled iterative superimposition algorithm (3,17,18). The resulting green (preoperative) and red (postoperative canal surface) color-coded root canal models enabled quantitative comparison of the matched root canals before and after shaping.

Firstly, virtual canal models were carefully inspected and scored for obvious forms of canal preparation errors. The smallest distance from the canal wall to the furcation (usually located in the coronal or middle root canal third) was measured in matched cross-sections before and after shaping by superimposing the virtual canal models.

Secondly, canal volumes up to the level of the cemento-enamel junction (CEJ) and in the apical 4 mm were determined using custom-made software (IPL, Scanco Medical) from individual canal models as described previously (17). Increases in volume and surface area were calculated by subtracting the scores for the treated canals from those recorded for the untreated counterparts. The amount of un-instrumented area was determined as a percentage of the number of static voxel surface to the total number of surface voxels from matched 3D before and after preparation models of the root canals.

The cross-sectional appearance (round or more ribbon-shaped) was determined with the so-called structure model index (SMI) (3,19). The SMI is a morphometric parameter, independent of the physical dimensions, that quantifies a characteristic form in terms of the amount of plates and rods composing a three-dimensional structure and varies from 0 (ideal plate structure) to 3 (ideal rod structure) depending on the volume ratio of rods and plates (19).

Canal transportation was determined by comparing the centres of gravity (calculated for each slice and connected along the z-axis with a fitted line) for apical, mid and coronal thirds of the canals before and after treatment.

Finally, the amount of remaining hard tissue debris was also determined by measuring the canal spaces that were visible in the preoperative scans but not in postoperative images from superimposed models.

Accumulated debris was calculated as described previously (14); in brief, volumes of canal spaces that were visible in the preoperative scans but not in postoperative images were determined from superimposed models.

Statistical analysis

Voxel volume in this data set was 8 x 10^{-6} mm^3 and such data is reported as means±S.D., rounded to the nearest $1/100mm^3$. All data was tabulated for further analysis. Prepared canal surface area was presented as percentages relative to preoperative canal surface areas and canal transportation was reported in µm distance.

Data from both groups were compared with Student T-test analysis after the verification of the compatibility with a normal distribution.

Results

Two molars in the Vortex and one in the TRUShape group had two completely independent canals and were excluded from the study. A TRUShape instrument fractured in sample number 2 (Figure 2) in the apical 3 mm. Therefore, data from 8 teeth per group were used for the analysis. Overall, both instruments appeared to prepare oval root canals without obvious preparation errors (Figure 1). Mean values and standard deviations of percentage of untreated area, percentage of debris, and differences in area (mm^2) and volume (mm^3) before and after the canal preparation in both the overall canal and the apical third are presented in Table 1. No significant differences were found in any of these parameters between TRUShape or Vortex root canal preparation of oval distal mandibular molar root canals.

There were no significant differences in canal transportation expressed as centre of mass (CM) shift after preparation of oval canals with TRUShape or Vortex; however, as shown in Table 1, means and standard deviations in Vortex group were higher due to preparations error detected. Although, canal transportation was typically below 150µm, CM shift data for tooth number 4 was higher than 300µm probably due to the presence of a bifurcation in the middle third after which the instrument did not follow one of the paths.

Differences from before and after in SMI and in distance to furcation as well as SMI morphometric parameters after canal preparation are also shown in table 1. Whilst no significant differences in preparation to the furcation compared to the initial distance were found between the 2 groups, the SMI shape factor was significantly lower for TRUShape preparations ($p=0.04$) suggesting less rounding during rotary shaping. As shown in Table 1, Vortex preparations are very close to an SMI of 3 and therefore to a theoretical rod structure (round preparation), compared to more ribbon-shaped TRUShape preparations (Figure 2).

Discussion

This *in vitro* study was designed as an initial assessment based on MCT reconstructions of the performance of a novel canal preparation instrument (TRUShape) compared to an established fixed-taper instrument (Vortex) in challenging asymmetrical non-round root canal anatomies. The selection of mandibular molar distal roots as an oval canal model has being previously validated (14,20). However, and despite all the efforts in standardization and randomization to have comparable groups, it was noted in this study a substantial variability in shape of distal canals in mandibular molars (Figure 1), as literature have reported before (9,21), what could have contributed to a substantial variation in some parameters of the data set as it can be observed in table 1. Serendipitously, new canal configurations have been found out of these 17 single distal canal mandibular molars not described in the literature before (Figure 3): 1-2-1-6 (sample 1), 1-2-1-10 (sample 2), 1-2-6 (sample 3), 1-7 (sample 4) and 1-2-4 (sample 5).

No significant differences were detected between both groups preparation in terms of percentage of untreated area, and increase in area (mm^2) and volume (mm^3) before and after the canal preparation in both the overall canal and the apical third. The amount of prepared canal surface has been the focus of several studies in oval root canals and greater variability has been found. Differences may be explained by the different selection of the volume of interest, much as the preparation technique itself. Overall, 50% of the root canal surface was left unprepared with #30/.06v TRUShape or #30/.06 Vortex instruments for both the entire canal and the apical third. Higher percentages have been previously reported when oval distal canals of mandibular molars were shaped with F4 (#40/.06) ProTaper instruments for both the entire canal (80%) or the apical third (65%) (20), while SAF instruments left 25% untreated canal surface when the whole canal length was considered and 40% when assessment was done in the apical 4 mm(22). Smaller percentages have also been reported in other studies when oval canals have been shaped to a 40/.06 Reciproc or 40/.04 BioRace (23), although measurement of unprepared surfaces was analyzed in absolute values instead of by analyzing the percentage of the number of static surface voxels to the total number of surface voxels before and after preparation. The authors concluded that the preparation strategy used with Reciproc or BioRace did not properly prepare non-round root canals (23).

The consequence of a large area of canal wall remaining untouched is that bacterial biofilms may remain adhered to the walls after root canal preparation. An *ex vivo* canal disinfection model consisting on extracted teeth contaminated with *Enterococcus faecalis* have demonstrated that the preparation of oval canals with SAF was significantly more effective than rotary NiTi instrumentation in reducing intracanal *E. faecalis* counts (24), however this experimental model provides information about bacterial persistence, but the location of persisting infection cannot be ascertained (25). In addition, when a combination of the shaping and disinfecting ability where combined in the same study, SAF demonstrated similar disinfecting and shaping performance than rotary NiTi instrumentation and a correlation between prepared canal surface and reduction in microbial burden could not be confirmed (25). It has also been recently demonstrated that TRUShape removed significantly more bacteria from the surface of oval root canal walls in the absence of antimicrobial irrigants than contemporary concentrically rotating nickel titanium instrument systems, although no significant differences were found when disinfecting solutions were used (26).

Preparation safety was another factor considered in the present study. Canal transportation was low in average for TRUShape group, in the same range of previous studies (14,20) for the apical and middle third and even lower in the coronal third, probably due to the maximum fluted diameter of TRUShape (0.8mm). At the same time, one TRUShape instrument fractured in one of the samples. Coronal enlargement was performed with #20/.08 instrument prior to negotiation and glide path preparation in Vortex group, but no preflaring was prepared before shaping with TRUShape instruments. It has been demonstrated that preflaring of the root canal may prevent rotary instrument fracture (27), although not specifically in single canals with oval configurations where coronal space might be enough to avoid stress and binding of the instrument along the canal wall. However, the challenging apical delta (Figure 2) might have prevented the achievement of a reproducible glide path causing the torsional breakage of the instrument that can occur when the canal cross section at that level is smaller than the tip of the instrument. On the contrary, no breakages occurred in Vortex group, but root canal preparations were associated with mean transportation scores higher than 100μm in the three canal thirds; although it has been determined that a "displacement of center of gravity of up to 150μm can be regarded as acceptable" (28) and the majority of the canals prepared in the current study did not exceed that standard.

Although no significant differences were found between both rotary instruments in the parameters stated above, special considerations, like how the instrument manages in bucco-lingual dimensions, should be considered when evaluating the geometry of final shapes created by instruments when working in oval canals. The tendency of the file to remain in the center (13,14) has classically created round preparations in all different canal configurations (6).

The Structure Model Index or SMI is a measurement of surface convexity and therefore a good parameter to evaluate non-round shapes. Samples with the same volume density but varying architecture can uniquely be characterized with SMI. This morphometric parameter makes it possible to quantify the characteristic form of a three-dimensionally described structure (19). The availability of 3D voxel-based datasets has driven the development of quantitative tools to extend morphometric capabilities to more realistic representations of the 3D structures. Algorithms that describe how plate-like or rod-like the structure is provide the size, shape and orientation of local morphometric, and improves the understanding of the structure as a whole. In the case of rod-like shapes, particles align along the layer in order to achieve the lowest possible occupied area, in contrast to plate-like morphologies (29).

When compared here to a conventional validated rotary system, Vortex, preparations of oval canals showed a significantly different SMI. TRUShape demonstrated the ability of creating more ribbon-shaped preparations compared to the round preparations that conventional rotary systems tend to prepare in non-round canal anatomies as shown in Figure 2. Prior studies have also noticed the importance of this parameter when shaping oval canals (3,14,16) and have reported higher values (more rounding) than those found in the present study for novel TRUShape. Self-adjusting file (SAF) instruments generated more complete shapes than rotary canal preparation in oval distal roots of mandibular molars, however SMI (2.71 ± 0.30) was also high (14). SMI values have also been reported for oval-shaped canals in single-rooted mandibular canines after preparation with either rotary or reciprocating instruments (16): SAF (SMI = 2.64 ± 0.29), WaveOne (SMI = 2.88 ± 0.13), Reciproc (SMI = 2.73 ± 0.44) and ProTaper (SMI = 2.80 ± 0.29). Other studies have measured roundness, instead of SMI, as an index varying from 0 (parallel plates) to 1 (perfect ball) in mandibular incisors after SAF preparation, although absolute postoperative values were not reported (15). To our knowledge, the SMI values for TRUShape found in the present study are the lowest for oval-shaped canals prepared with any tested shaping instrument described in the endodontic literature, and therefore the instrument seems to provide the most ribbon-shaped preparation reported so far.

The use of TRUShape rotaries has been previously reported in round canal cross-sections. Although its use in mesial roots of mandibular molars did not result in increased amounts of treated canal surface when compared with Vortex rotary instruments, TRUShape resulted in a significantly higher conservation of dentin by limited dentin removal with minimal canal transportation (30).

Within the limitations of this *in vitro* study, the results suggest that although both instruments are suitable for the preparation of oval canals, TRUShape better conformed the original ribbon-shaped anatomy.

References:

1. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18:269–96.
2. Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod 1988;14:346–51.
3. Peters OA, Laib A, Rüegsegger P, Barbakow F. Three-dimensional analysis of root canal geometry by high-resolution computed tomography. J Dent Res 2000;79:1405–9.
4. Peters OA, Schönenberger K, Laib A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. Int Endod J 2001;34:221–30.
5. Wu MK, Wesselink PR. A primary observation on the preparation and obturation of oval canals. Int Endod J 2001;34:137–41.
6. Evans GE, Speight PM, Gulabivala K. The influence of preparation technique and sodium hypochlorite on removal of pulp and predentine from root canals of posterior teeth. Int Endod J 2001;34:322–30.
7. Wu M-K, R'oris A, Barkis D, Wesselink PR. Prevalence and extent of long oval canals in the apical third. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:739–43.
8. Grande NM, Plotino G, Pecci R, Bedini R, Pameijer CH, Somma F. Micro–computerized tomographic analysis of radicular and canal morphology of premolars with long oval canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:e70–6.
9. Filpo-Perez C, Bramante CM, Villas-Boas MH, Húngaro Duarte MA, Versiani MA, Ordinola-Zapata R. Micro-computed tomographic analysis of the root canal morphology of the distal root of mandibular first molar. J Endod 2015;41:231–6.
10. Wu MK, Dummer PMH, Wesselink PR. Consequences of and strategies to deal with residual post-treatment root canal infection. Int Endod J 2006;39:343–56.
11. Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging

prevailing paradigms. Br Dent J 2014;216:347–53.

12. Zelic K, Vukicevic A, Jovicic G, Aleksandrovic S, Filipovic N, Djuric M. Mechanical weakening of devitalized teeth: three-dimensional Finite Element Analysis and prediction of tooth fracture. Int Endod J 2015;48:850-63.

13. Metzger Z, Zary R, Cohen R, Teperovich E, Paqué F. The quality of root canal preparation and root canal obturation in canals treated with rotary versus Self-adjusting Files: A three-dimensional micro-computed tomographic study. J Endod 2010;36:1569–73.

14. Paqué F, Peters OA. Micro-computed tomography evaluation of the preparation of long oval root canals in mandibular molars with the self-adjusting file. J Endod 2011;37(4):517–21.

15. Versiani MA, Pécora JD, de Sousa-Neto MD. Flat-oval root canal preparation with self-adjusting file instrument: a micro-computed tomography study. J Endod 2011;37:1002–7.

16. Versiani MA, Leoni GB, Steier L, De-Deus G, Tassani S, Pécora JD, et al. Micro-computed tomography study of oval-shaped canals prepared with the self-adjusting file, Reciproc, WaveOne, and ProTaper universal systems. J Endod 2013;39:1060–6.

17. Paqué F, Ganahl D, Peters OA. Effects of root canal preparation on apical geometry assessed by micro–computed tomography. J Endod 2009;35:1056–9.

18. Peters OA, Barbakow F. Effects of irrigation on debris and smear layer on canal walls prepared by two rotary techniques: a scanning electron microscopic study. J Endod 2000;26:6–10.

19. Hildebrand T, Rüegsegger P. Quantification of bone microarchitecture with the structure model index. Comput Methods Biomech Biomed Engin 1997;1:15–23.

20. Paqué F, Balmer M, Attin T, Peters OA. Preparation of oval-shaped root canals in mandibular molars using nickel-titanium rotary instruments: a micro-computed

tomography study. J Endod 2010;36:703–7.

21. Vertucci FJ. Root canal morphology and its relationship to endodontic procedures. Endod Topics 2005;10:3–29.

22. Paqué F, Boessler C, Zehnder M. Accumulated hard tissue debris levels in mesial roots of mandibular molars after sequential irrigation steps. Int Endod J 2011;44:148–53.

23. Busquim S, Cunha RS, Freire L, Gavini G, Machado ME, Santos M. A micro-computed tomography evaluation of long-oval canal preparation using reciprocating or rotary systems. Int Endod J 2015;48:1001-16.

24. Siqueira JF Jr, Alves FRF, Almeida BM, Machado de Oliveira JC, Rôças IN. Ability of chemomechanical preparation with either rotary instruments or Self-adjusting File to disinfect oval-shaped root canals. J Endod 2010;36:1860–5.

25. Siqueira JF, Alves FRF, Versiani MA, Rôças IN, Almeida BM, Neves MAS, et al. Correlative bacteriologic and micro-computed tomographic analysis of mandibular molar mesial canals prepared by self-adjusting file, reciproc, and twisted file systems. J Endod 2013;39:1044–50.

26. Bortoluzzi EA, Carlon D, Meghil MM, El-Awady AR, Niu L, Bergeron BE, et al. Efficacy of 3D conforming nickel titanium rotary instruments in eliminating canal wall bacteria from oval-shaped root canals. J Dent 2015;43:597–604.

27. Roland DD, Andelin WE, Browning DF, Hsu G-HR, Torabinejad M. The effect of preflaring on the rates of separation for 0.04 taper nickel titanium rotary instruments. J Endod 2002;28:543–5.

28. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559–67.

29. Stauber M, Rapillard L, van Lenthe GH, Zysset P, Müller R. Importance of individual rods

and plates in the assessment of bone quality and their contribution to bone stiffness. J Bone Miner Res 2006;21:586–95.

30. Peters OA, Arias A, Paqué F. A Micro-computed tomographic assessment of root canal preparation with a novel instrument, TRUShape, in mesial roots of mandibular molars. J Endod 2015;41:1545–50.

Tables

Table 1. Quantitative assessment of canal preparation for TRUShape and Vortex (Mean ± SD).

(*) Indicates statistical significant differences between groups.

			TRUShape	Vortex
Overall (software calculations)	Unprepared surface (%)		55.83 ± 13.76	50.64 ± 13.22
	Debris (%)		0.25 ± 0.22	0.20 ± 0.17
	Center mass shift (µm)	Coronal	69.63 ± 40.78	109.50 ± 95.51
		Middle	87.63 ± 42.52	115.75 ± 145.84
		Apical	77.13 ± 54.18	134.25 ± 110.5
	Difference pre-post	Area (mm^2)	2.33 ± 1.28	3.25 ± 2.4
		Volume (mm^3)	2.02 ± 1.11	2.26 ± 1.11
		SMI (dimensionless)	0.34 ± 0.34*	0.78 ± 0.45*
	SMI post (dimensionless)		2.14 ± 0.44*	2.85 ± 0.36*
Apical third (software calculations)	Unprepared surface (%)		49.96 ± 19.71	51.03 ± 14.67
	Debris (%)		0.08 ± 0.06	0.08 ± 0.09
	Difference pre-post	Area (mm^2)	0.85 ± 0.89	0.37 ± 0.72
		Volume (mm^3)	0.32 ± 0.2	0.28 ± 0.14
Cross-section (virtual canal model)	Differences pre-post	Distance to furcation (mm)	0.19 ± 0.08	0.25 ± 0.17

Figure legends

Figure 1. Three-dimensional appearance of a mandibular molar, with the distal canal prepared with TRUShape (a) and Vortex (b) after shaping to sizes #30.

Figure 2. a) Apical delta of specimen number 2 in Group 2 where TRUShape instrument fractured. b) Coronal cross-sections after TRUShape preparation (SMI=2.14±0.44). Notice the ribbon-shaped preparation. c) Coronal cross-sections after Vortex preparation (SMI=2.85±0.36). Notice that white line indicates the original root canal contour and green shape shows instrument preparation in both 2b and 2c.

Figure 3. New canal configurations found in the study.